California Energy Commission -- Committee Workshop on Clean Coal Technology and Carbon Capture and Storage

Meeting GHG Reduction Targets in California with Biofuels and Carbon Sequestration

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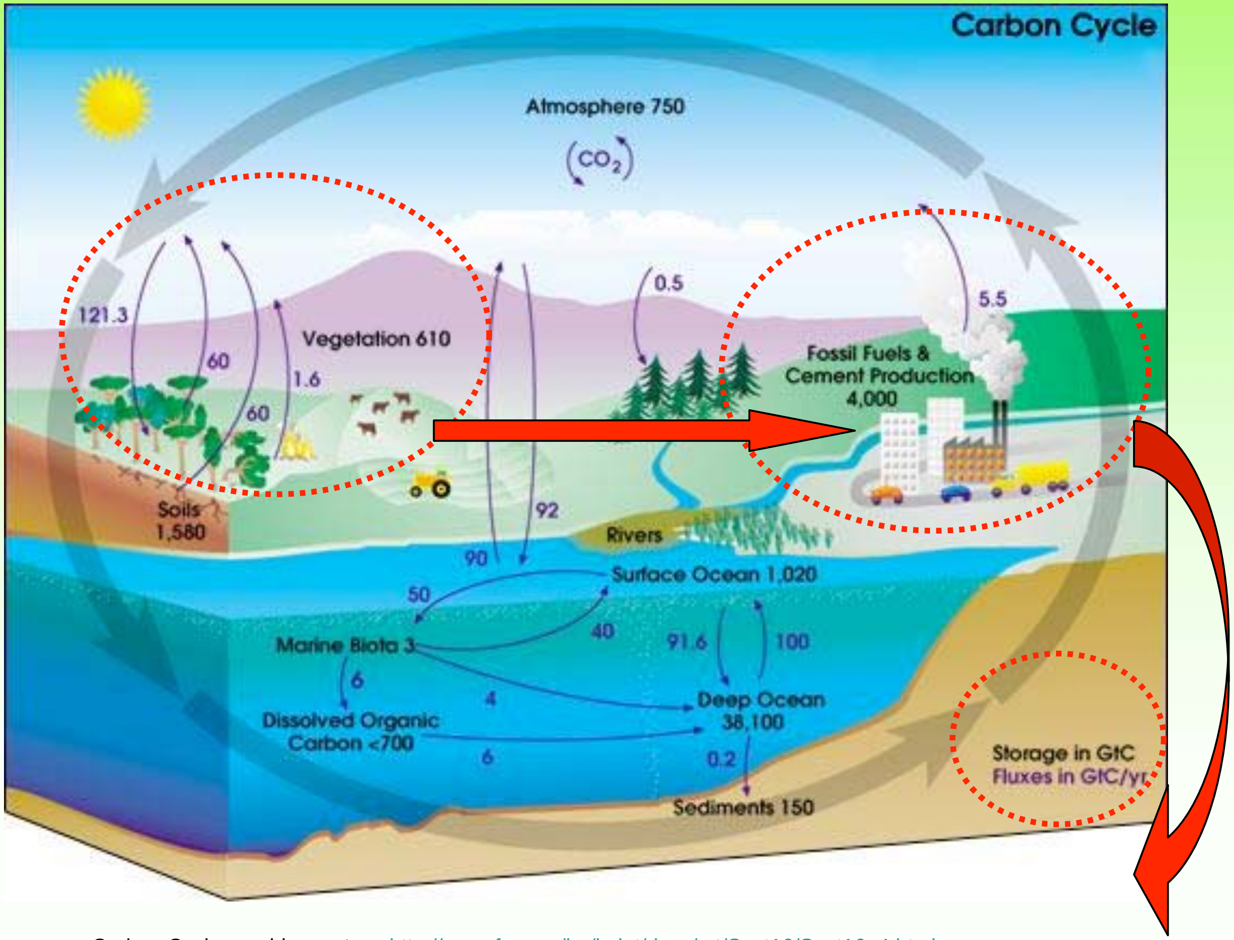
Summary

- **Terrestrial Sequestration Options for California**
  - Afforestation
  - Conservation Management
  - Managing Fires
- **Biofuels Options for California**
- **Geologic Sequestration of CO_2 Associated with Biofuels Production in California**

Plants and the Atmosphere

- Plants have proven ability to remove CO_2 from the atmosphere
- Plants can be converted to biofuels with CO_2 byproduct

  → geologic sequestration of byproduct CO_2 is the only cost-effective option available to reduce atmospheric concentrations of CO_2

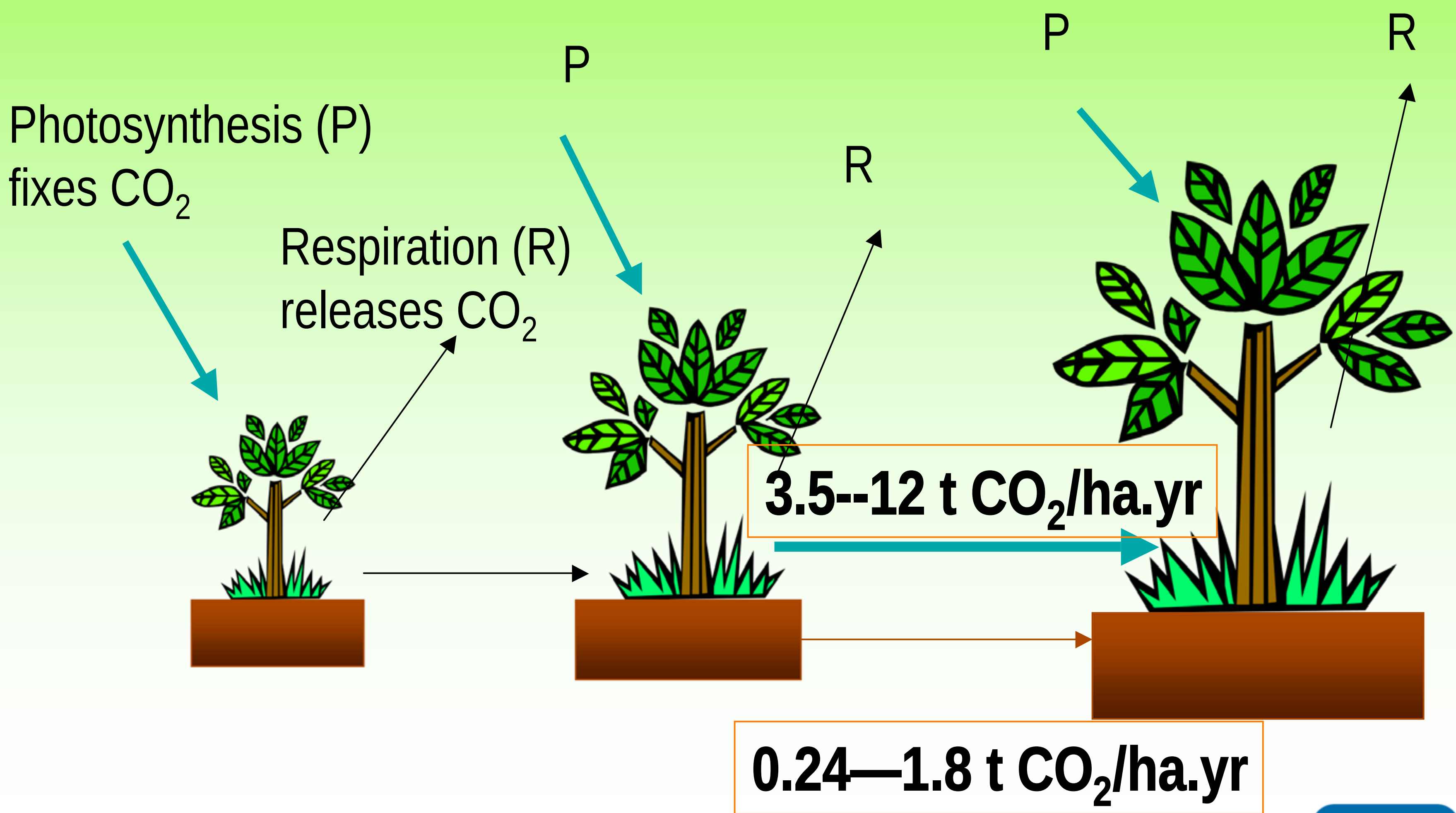


Carbon Cycle graphic courtesy http://www.fas.org/irp/imint/docs/rst/Sect16/Sect16_4.html

Can Biofuels and Sequestration Make a Difference?

- Ethanol
  - 424 million gallons per year producing ~800,000 metric tons of CO_2 available for geologic sequestration
- Reducing hazardous fuels
  - 16 million acres at high/very high risk of fire
  - Treating 15% would yield ~ 48 million metric tons of fuel
  - Thermochemical pathway to biofuel would yield ~ 132 million gallons of biofuel per year for 20 years with ~ 1 million metric tons of CO_2 available for geologic sequestration
- Terrestrial Sequestration
  - Afforestation of 15% of available rangelands over 40 years would sequester ~ 11 million metric tons of CO_2 per year

How Do Ecosystems Sequester Carbon?

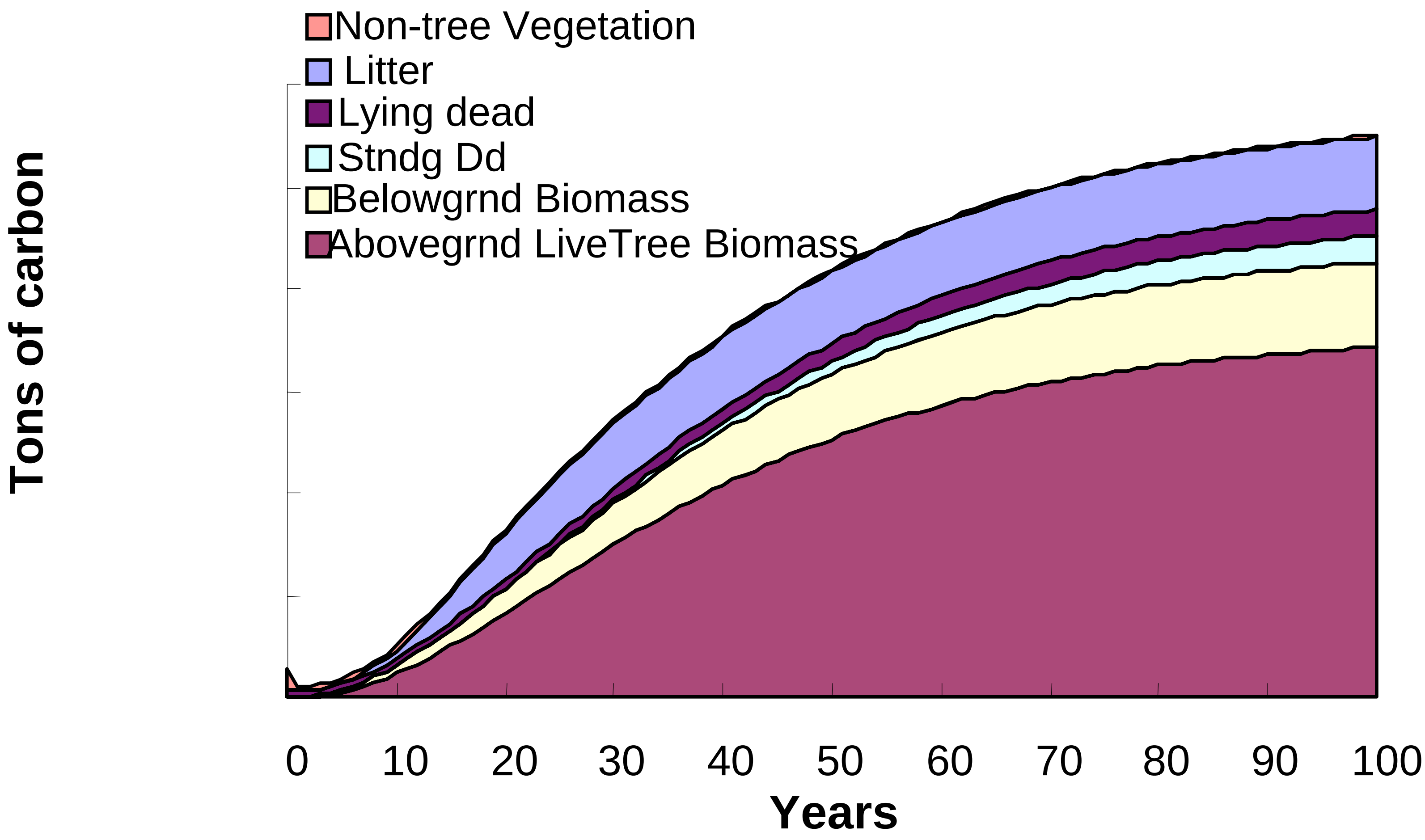


Where is Carbon Sequestered?

- Live biomass
  - Trees
  - Understory
  - Roots
- Dead biomass
  - Standing
  - Down
    - Coarse
    - Fine
- Wood products
- Soil

"Carbon Pools"

Carbon Accumulation



California Annual Emissions and Removals by Cause of Change for 1994-2000

$MMTCO_2$/yr	Forests	Rangelands
Fire	-1.55	-0.14
Harvest	-1.40	-0.03
Development	-0.01	-0.004
Other/Unverified	-0.79	-0.10
Regrowth	+10.96	+0.46

Estimating Terrestrial Carbon Sequestration for California

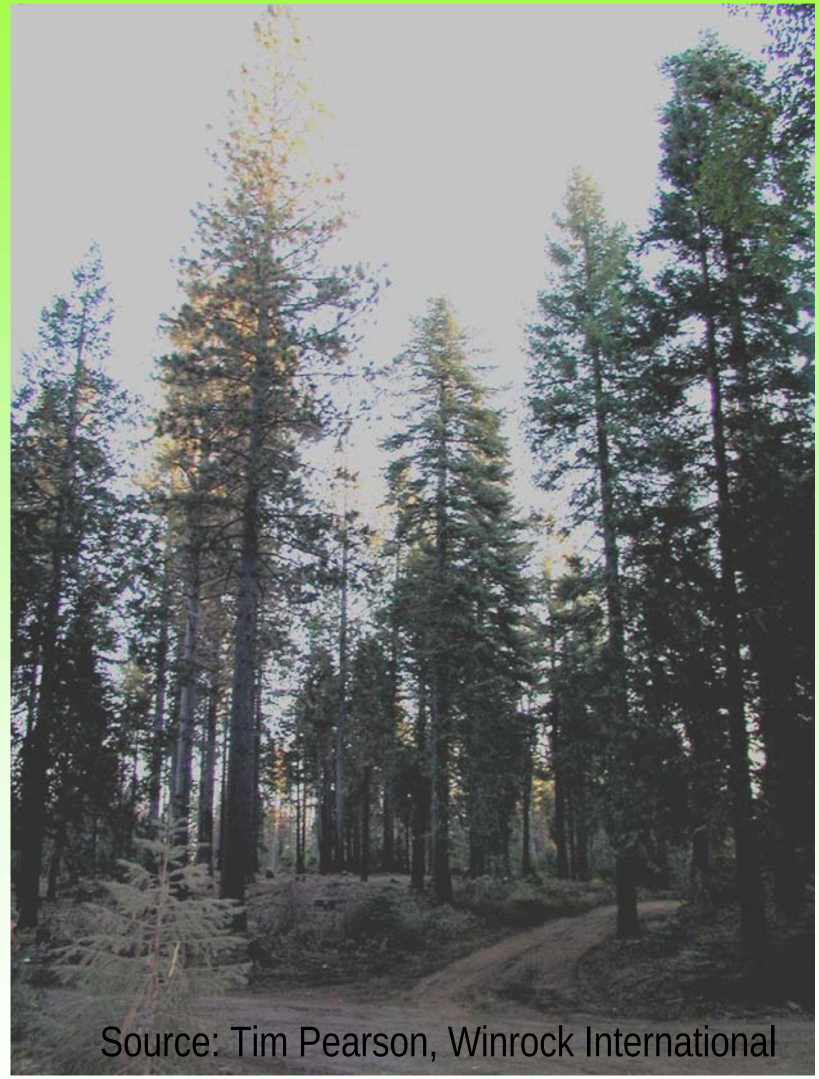
- Identified options for:
  - Rangelands
  - Forests
  - Agriculture
- Estimated:
  - Area available—how much and where
    - Spatial modeling and FIA data base
  - Amount of carbon sequestration over 20, 40, and 80 year periods
  - Costs (opportunity costs, conversion costs, maintenance costs, and measuring costs)

Primary Terrestrial Sequestration Findings

- Afforestation provides the largest terrestrial sequestration opportunity for California
- Large areas of grazing land suitable for afforestation can be found
- Conservation and changes in management practices on forest lands can sequester additional carbon
- Methodologies being developed to quantify potential sequestration from changing fire management practices on forest lands

Afforestation

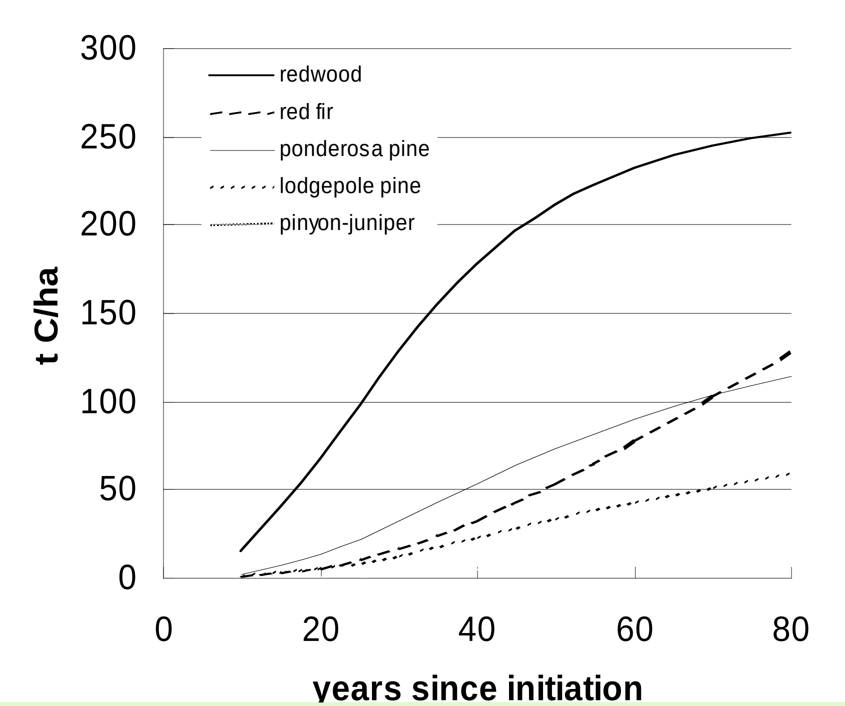
- Convert agricultural or grazing land back to forest
  - Return to native forest
  - Convert to forest land for timber production

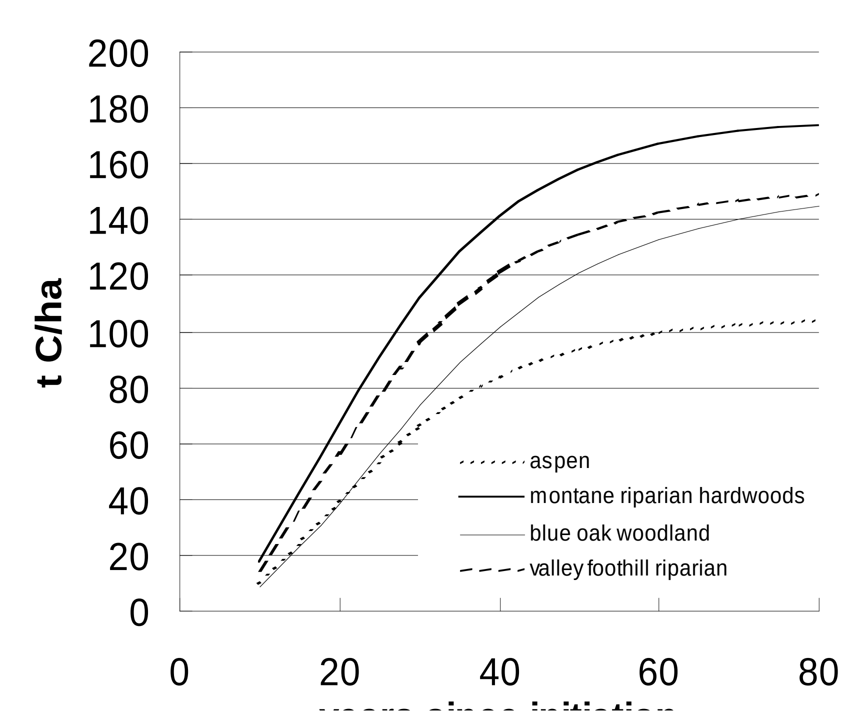


Source: Tim Pearson, Winrock International

Mixed Conifers

Potential Carbon Accumulation in Conifer and Hardwood Forests



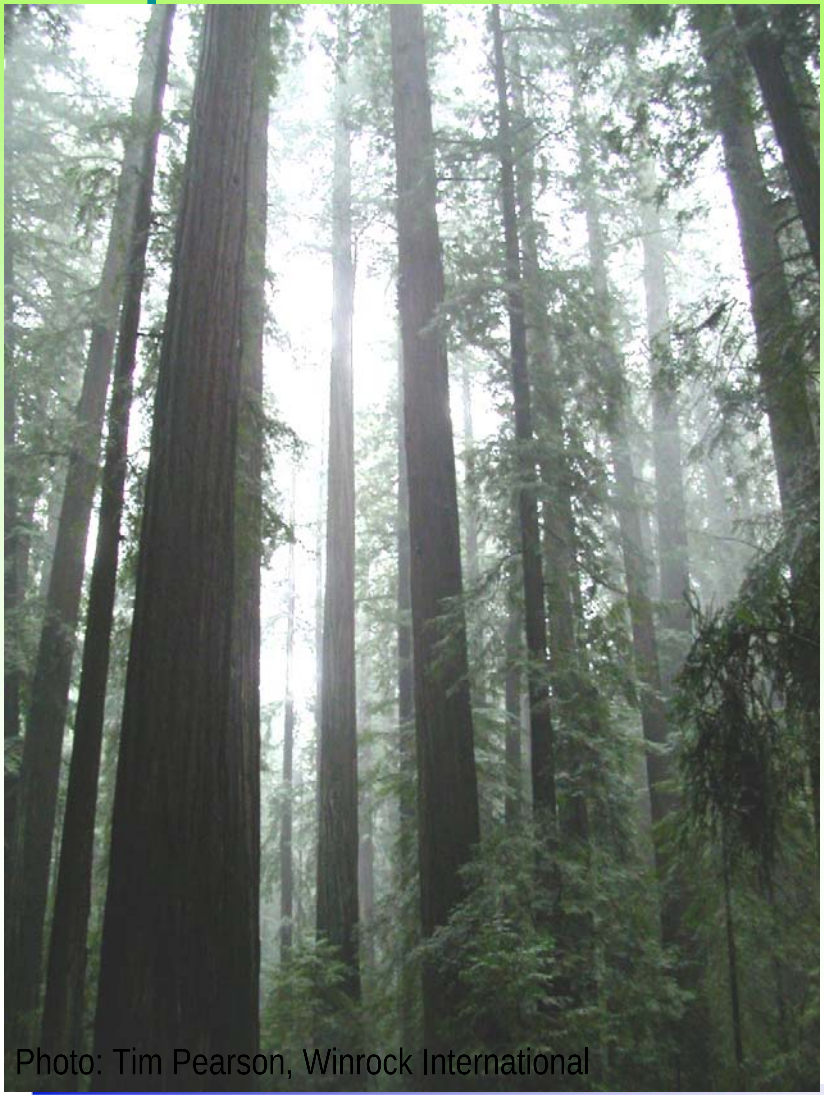


Magnitude and Cost of Afforestation

Afforestation of grazing lands provides the most carbon and at the least cost

Activity	Quantity of C —MMT CO_2			Area available—M acres		
	20 yr	40 yr	80 yr	20 yr	40 yr	80 yr
Forest management						
Lengthen rotation						
<$13.6	**2.2-3.5**	--	--	0.31	--	--
Increase riparian buffer -width						
<$13.6		**3.91** (permanent)			0.044	
Grazing lands						
Afforestation						
<$13.6	**887**	3,256	5,639	12.03	17.79	20.76
<$2.7	33	1,610	4,569	0.20	5.68	13.34

Conservation and Forest Management



- Stop forest conversion to non-forest
- Increase carbon stocks within existing forests
- Sierra Mixed Conifer (150 year old forest)
  - 575 tCO_2/acre
- Redwood (150 year old forest)
  - 730 tCO_2/acre

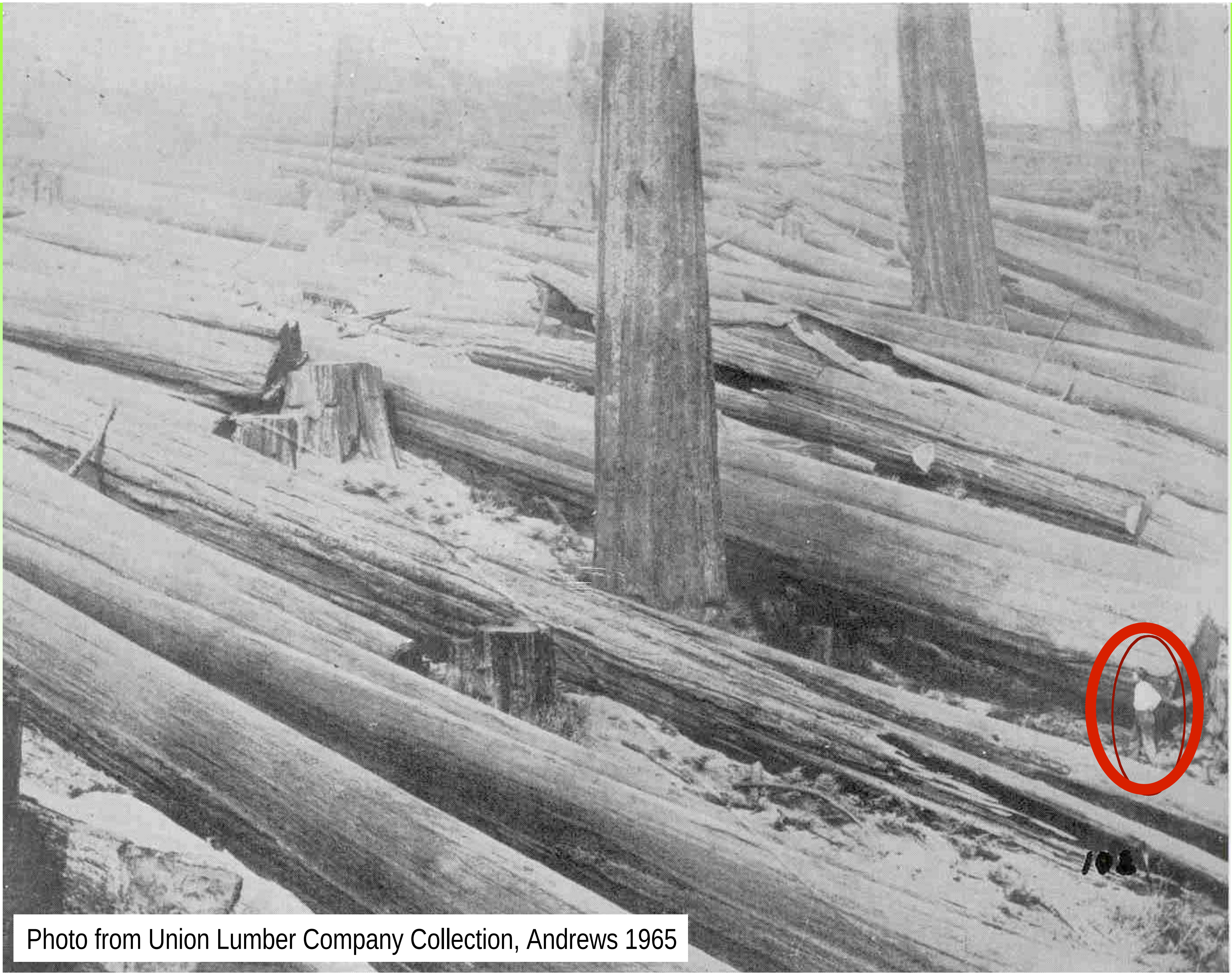
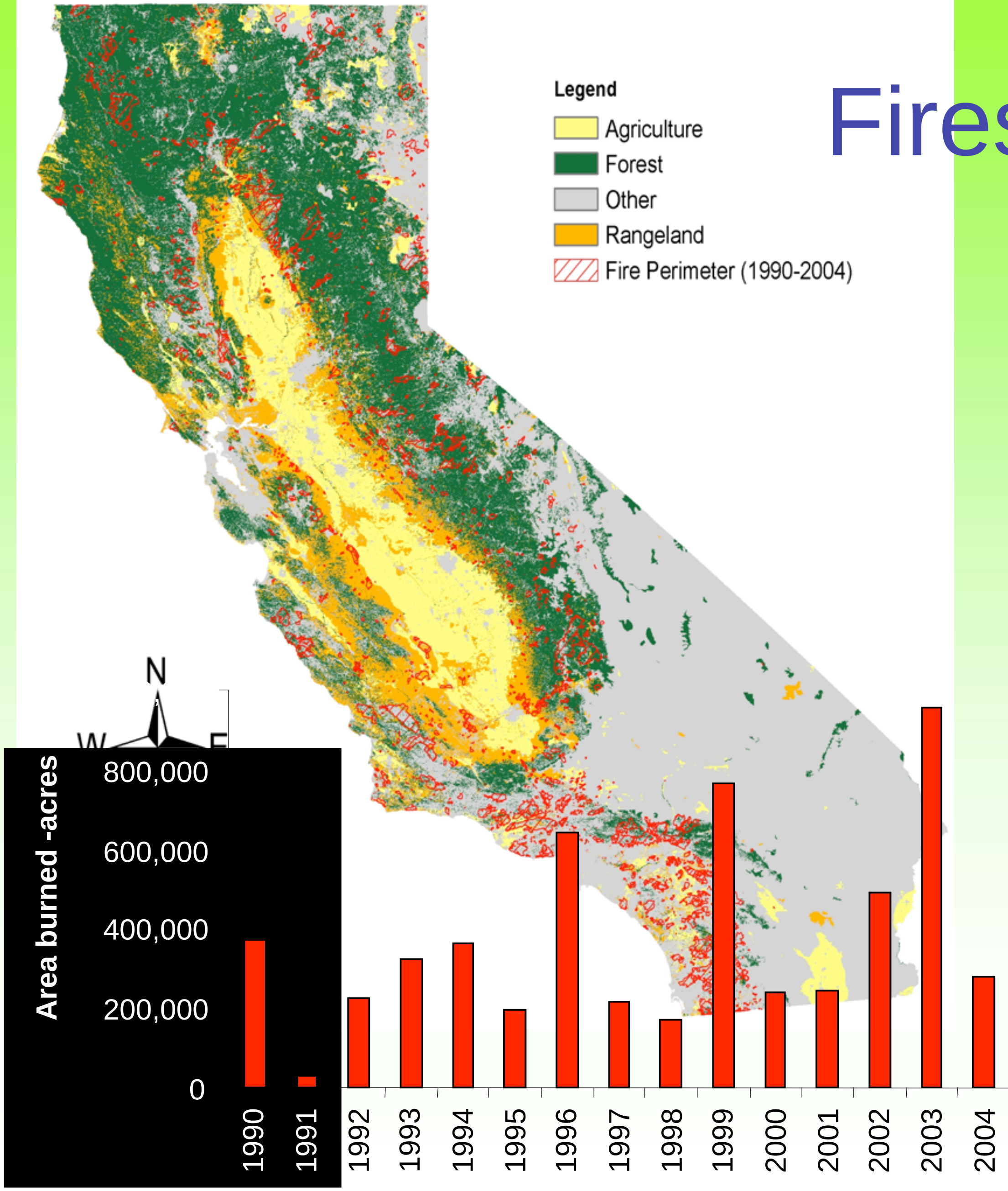


Photo from Union Lumber Company Collection, Andrews 1965

Fires in California



Total area burned in 1990-2004 = 5.5 million acres

Emissions from fires during period ~ 26 MMT CO_2 plus other GHGs

Potential Sequestration Benefits from Improved Fire Management

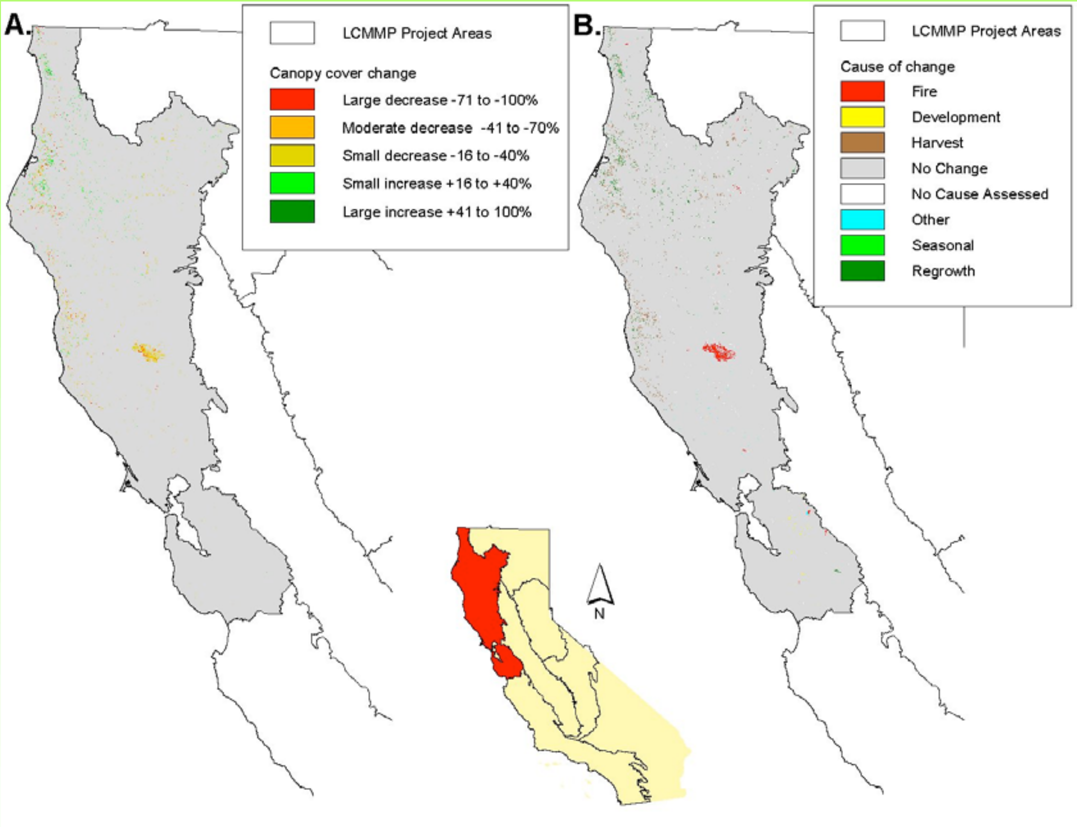
Source: Dr. Sam Sandberg, USDA Forest Service
PacificWildland Fire Sciences Laboratory

- Reduce loss of carbon stocks from large trees, litter and soil
- Reduce area burned
- Maintain carbon accumulation rates during recovery
- Reduce non-CO_2 GHG emissions
- Avoid ecosystem-changing fires
- Offset fossil fuel emissions

Not all fires are the same

Photos: Dr. Sam Sandberg, USDA Forest Service
Pacific Wildland Fire Sciences Laboratory

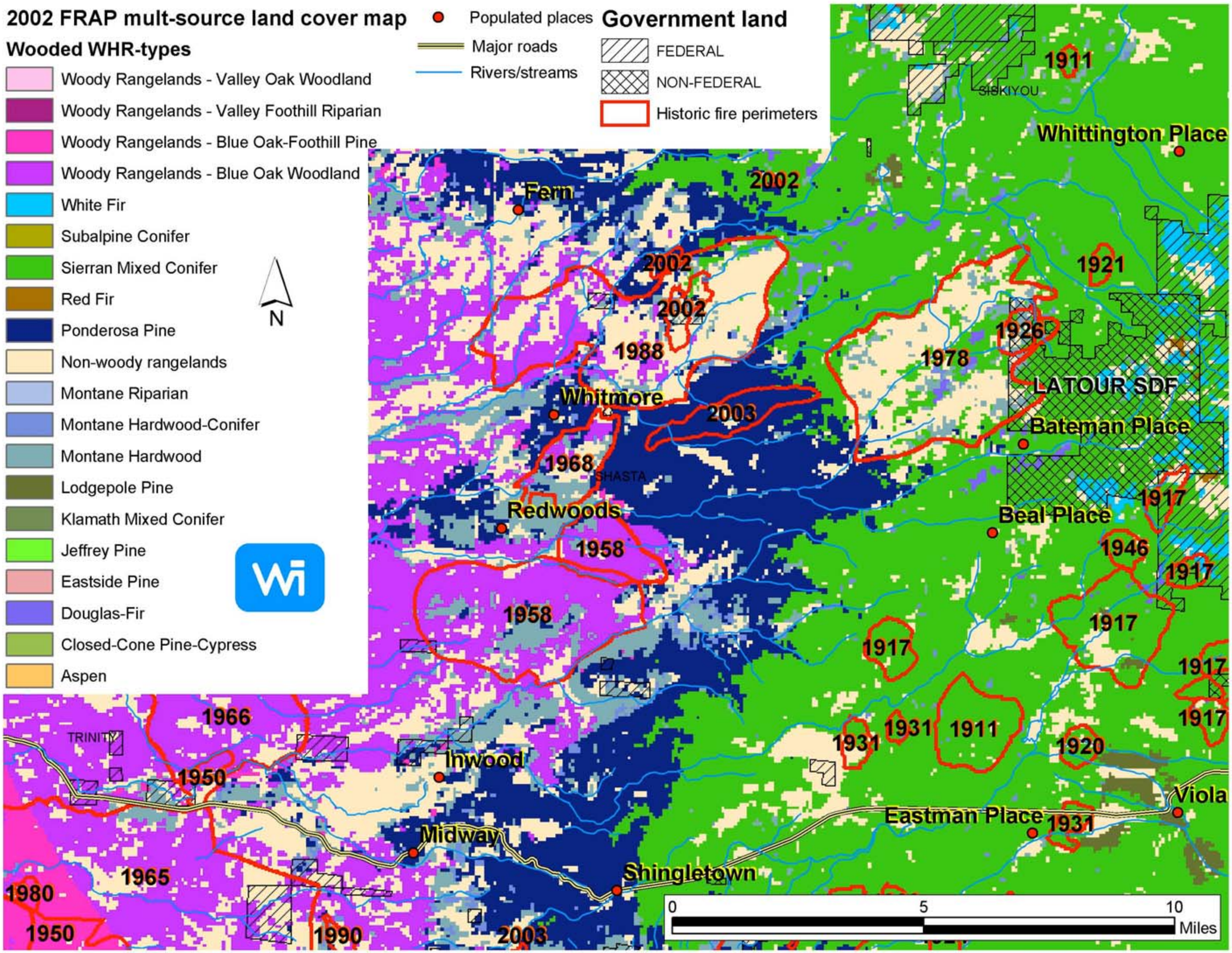
California Statewide Analysis



Fire as a cause of canopy cover change:

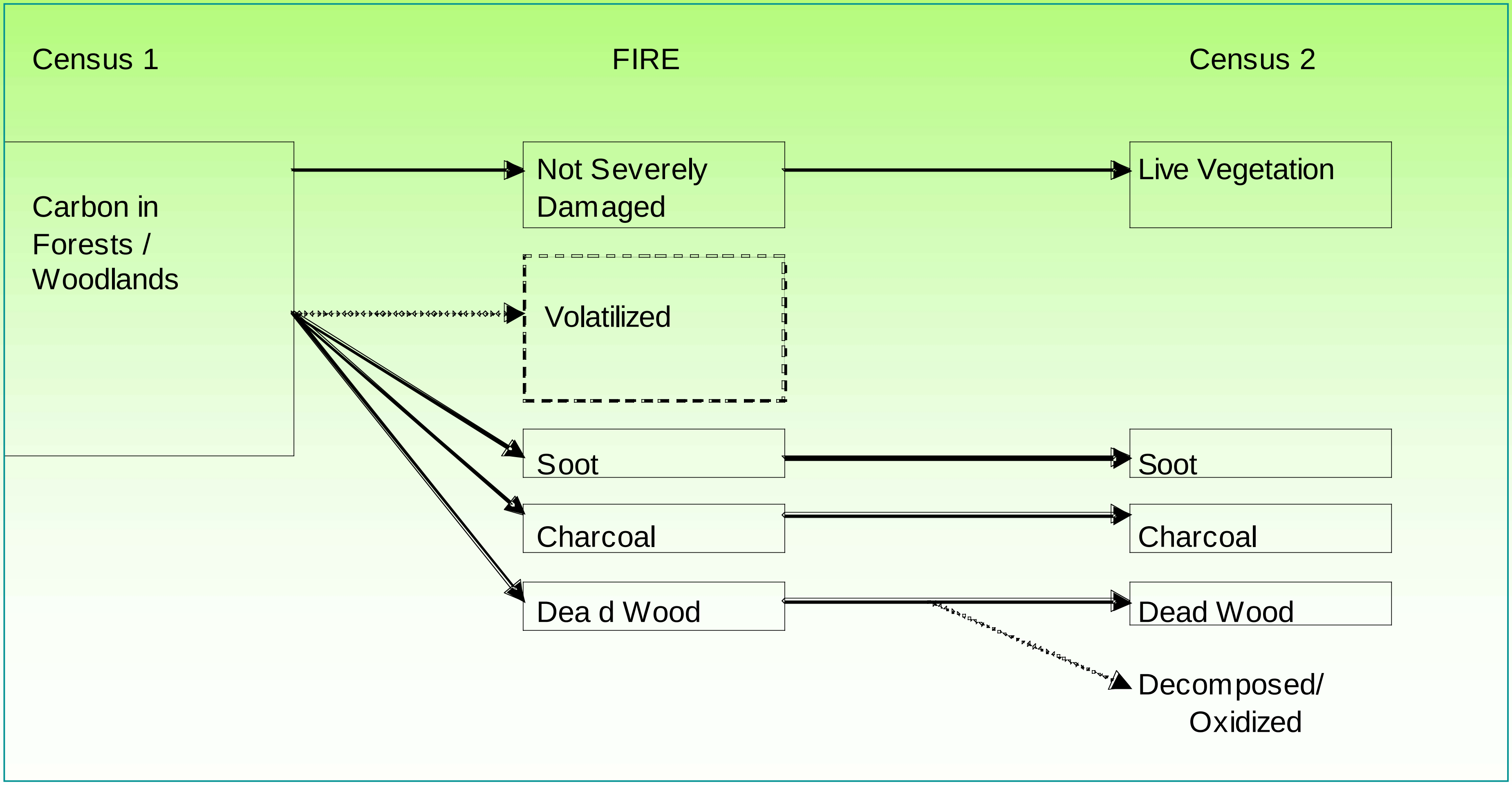
- 18% of total change in North Coast region
- 12% in Cascade Northeast region
- 47% in Northern Sierra

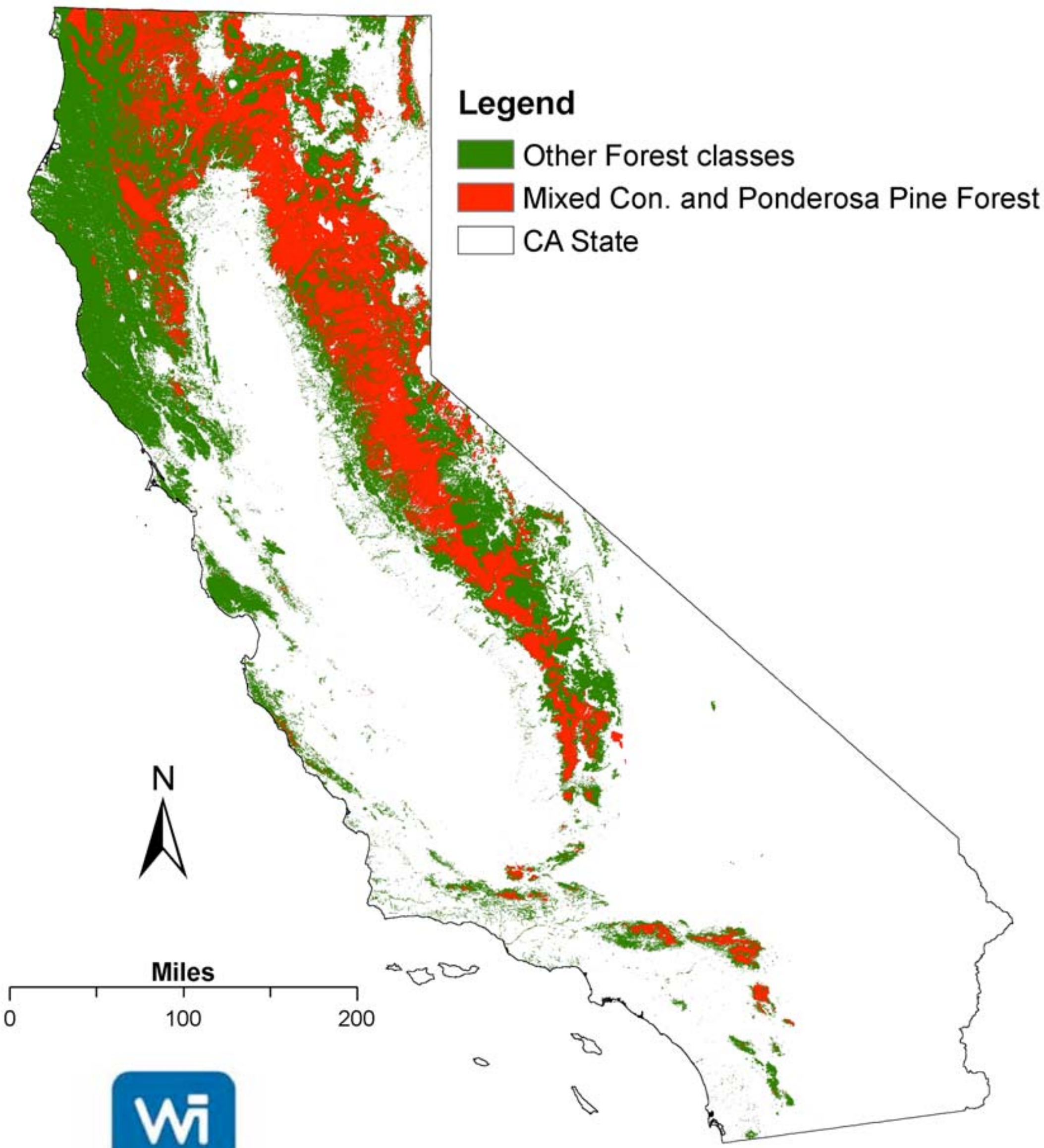
Source: CDF-FRAP LCMMP



2002 FRAP mult-source land cover map
Wooded WHR-types
Woody Rangelands - Valley Oak Woodland
Woody Rangelands - Valley Foothill Riparian
Woody Rangelands - Blue Oak-Foothill Pine
Woody Rangelands - Blue Oak Woodland
White Fir
Subalpine Conifer
Sierran Mixed Conifer
Red Fir
Ponderosa Pine
Non-woody rangelands
Montane Riparian
Montane Hardwood-Conifer
Montane Hardwood
Lodgepole Pine
Klamath Mixed Conifer
Jeffrey Pine
Eastside Pine
Douglas-Fir
Closed-Cone Pine-Cypress
Aspen
Populated places
Major roads
Rivers/streams
Government land
FEDERAL
NON-FEDERAL
Historic fire perimeters
N
SISKIYOU
SHASTA
TRINITY
Whittington Place
Fern
Whitmore
Redwoods
LATOUR SDF
Bateman Place
Beal Place
Inwood
Midway
Shingletown
Eastman Place
Viola
1911
2002
1921
1926
1978
1988
2003
1968
1958
1917
1946
1931
1920
1966
1950
1965
1980
1990
0
5
10
Miles

What Happens to Carbon Stocks in a Fire?





CA forests at high/ very high risk of fire that could benefit from treatment = 16.2 million acres

Estimated net emissions from these forests if they burned range from 80 - 185 t CO_2/ha)

About 2.2 million acres currently meet constraints for treatment

Constraints: Slope, yarding distance, block size and distance to biomass plant

Cost Equation

- Improve economics of fuel breaks and ladder fuel reduction
- Find highest and best use for all material generated
- Shift resources from fire suppression to fire prevention
- Improve incentives for fuel reduction, maintenance, post-fire salvage and restoration

Can carbon markets contribute to a solution?

Sequestration Issues

- Baselines
- Permanence
- Additionality
- Leakage
  - Activity-shifting
  - Market-based

Biofuels Options

- Lipid or Oleo Chemical
  - Vegetable oils
  - Animal fats
- Biochemical
  - Sugars to ethanol
  - Cellulose to ethanol
- Thermochemical
  - Syngas with catalysts

Several Biofuel Options Also Yield CO_2

Liquid Fuels

Biological Fermentation
(i.e. ethanol)

Thermochemical
(w/ F-T processing)

Electricity

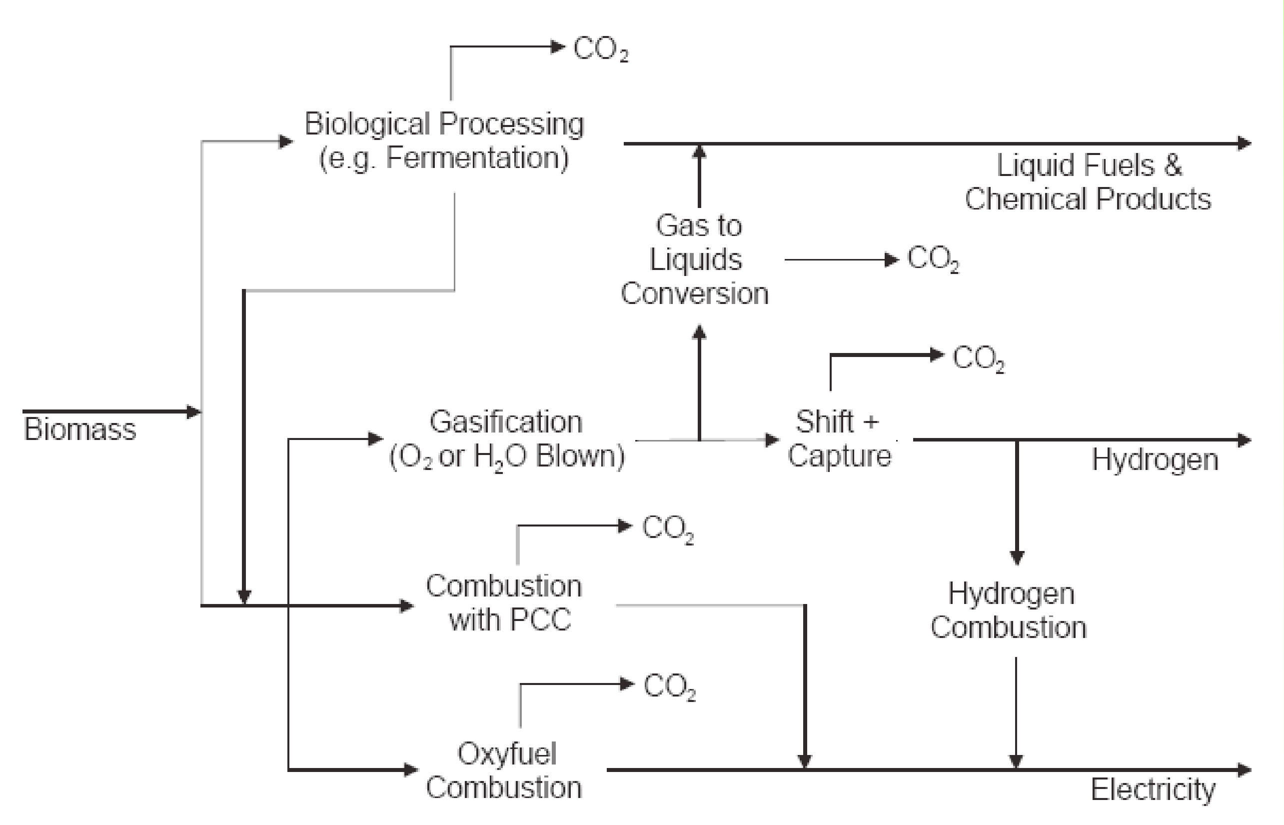
Simple Combustion

Biogas Digestion

Oxyfuel Combustion

Gasification (IGCC)

Co-firing biomass with fossil fuel (i.e. coal)



Rhodes and Keith 2005, "Engineering economic analysis of biomass IGCC with CCS"

California Ethanol Plants

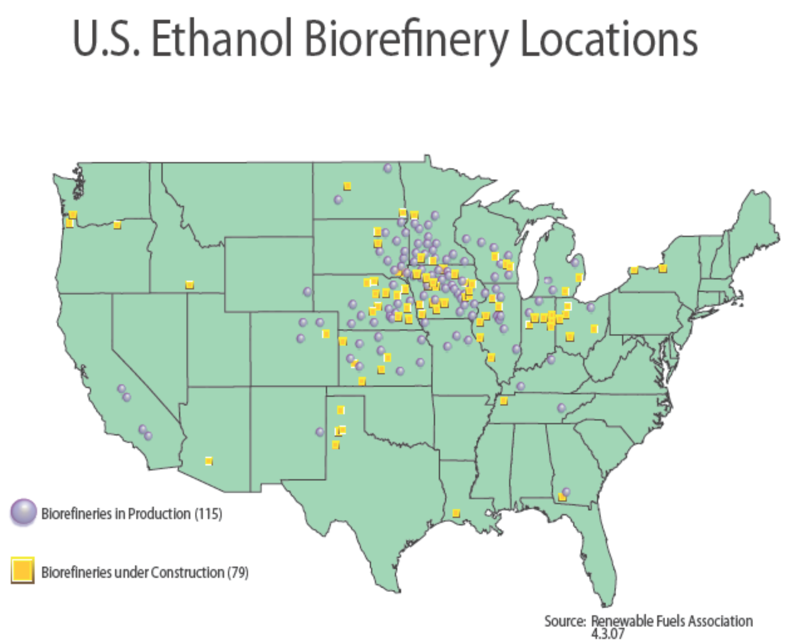
- Two large operating plants in California:
  - **Goshen: 25 MMgy**
  - **Madera: 35 MMgy**
- Five additional plants under development with additional 340 MMgy
- BlueFire 24 MMgy cellulosic ethanol from waste plant in Corona, CA
- CO_2 production from 424 million gallon/yr plant will be about 800,000 mt of CO_2 per year (4.2 lbs CO_2 per gallon ethanol)

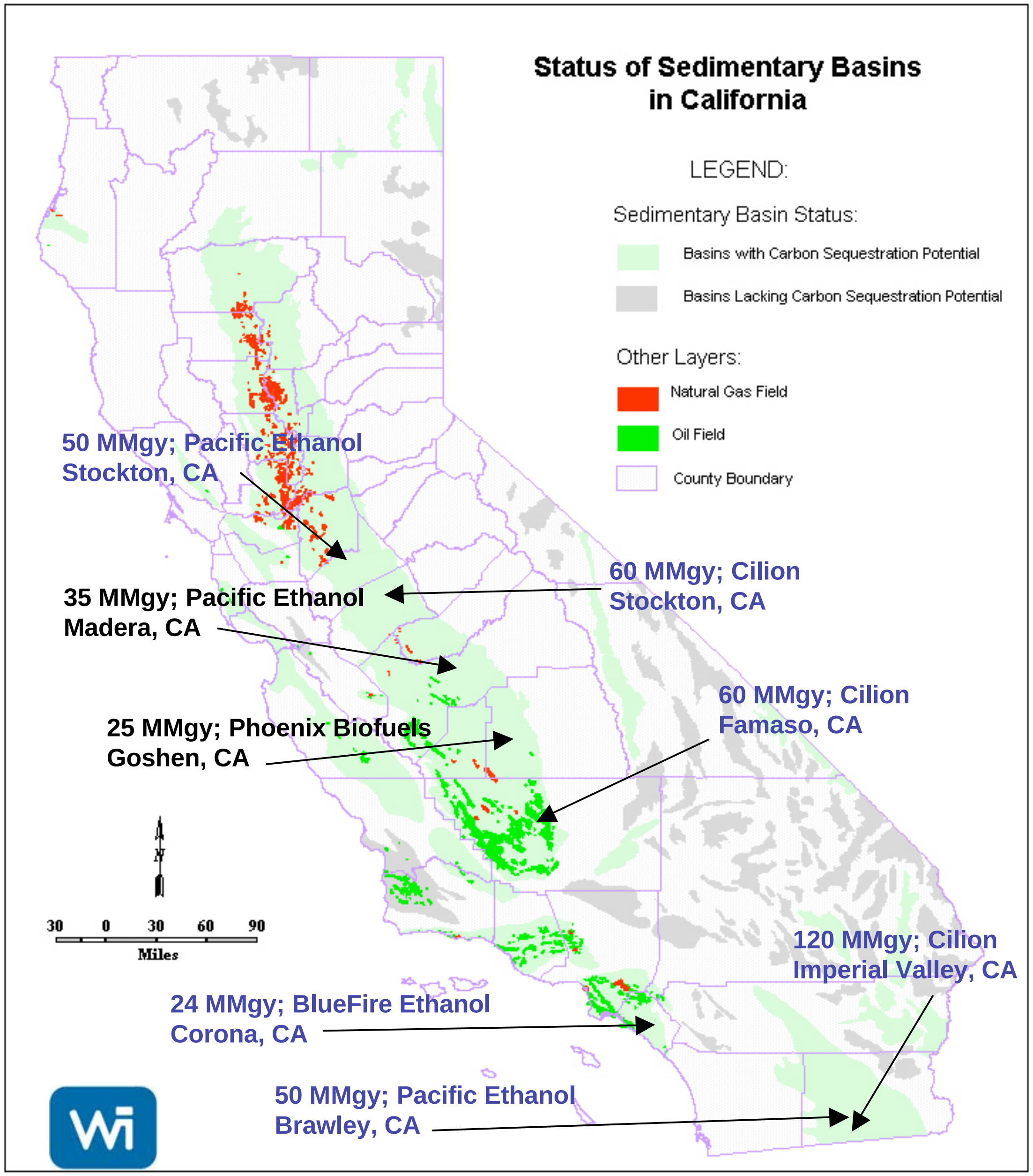
Pacific Ethanol Madera Refinery

Courtesy: Pacific Ethanol

Ethanol Locations in California

- Existing ethanol facilities are located near potential geologic sinks…
- … as are **proposed** plants





Ethanol Fermentation Gas

Component	Concentration
Carbon Dioxide	**> 99.0% by volume**
Water	No free water
Nitrogen	< 150 ppmv
Oxygen	< 30 ppmv
Total Hydrocarbons**	< 1000 ppmv as Methane
Total Volatile Organic Compounds (not including ethanol)	< 10 ppmv
Ethanol	< 100 ppmv
Aldehydes	< 5.0 ppmv
Benzene	< 0.01 ppmv
Hydrogen Sulfide	< 0.1 ppmv
Carbonyl Sulfide	< 0.1 ppmv
Total Sulfur (as H_2S)	< 1.0 ppmv
Residual foreign matter***	< 10.0 ppmw
Temperature	Equal to or less than 85^{o} F
Pressure	> 1.0 psig

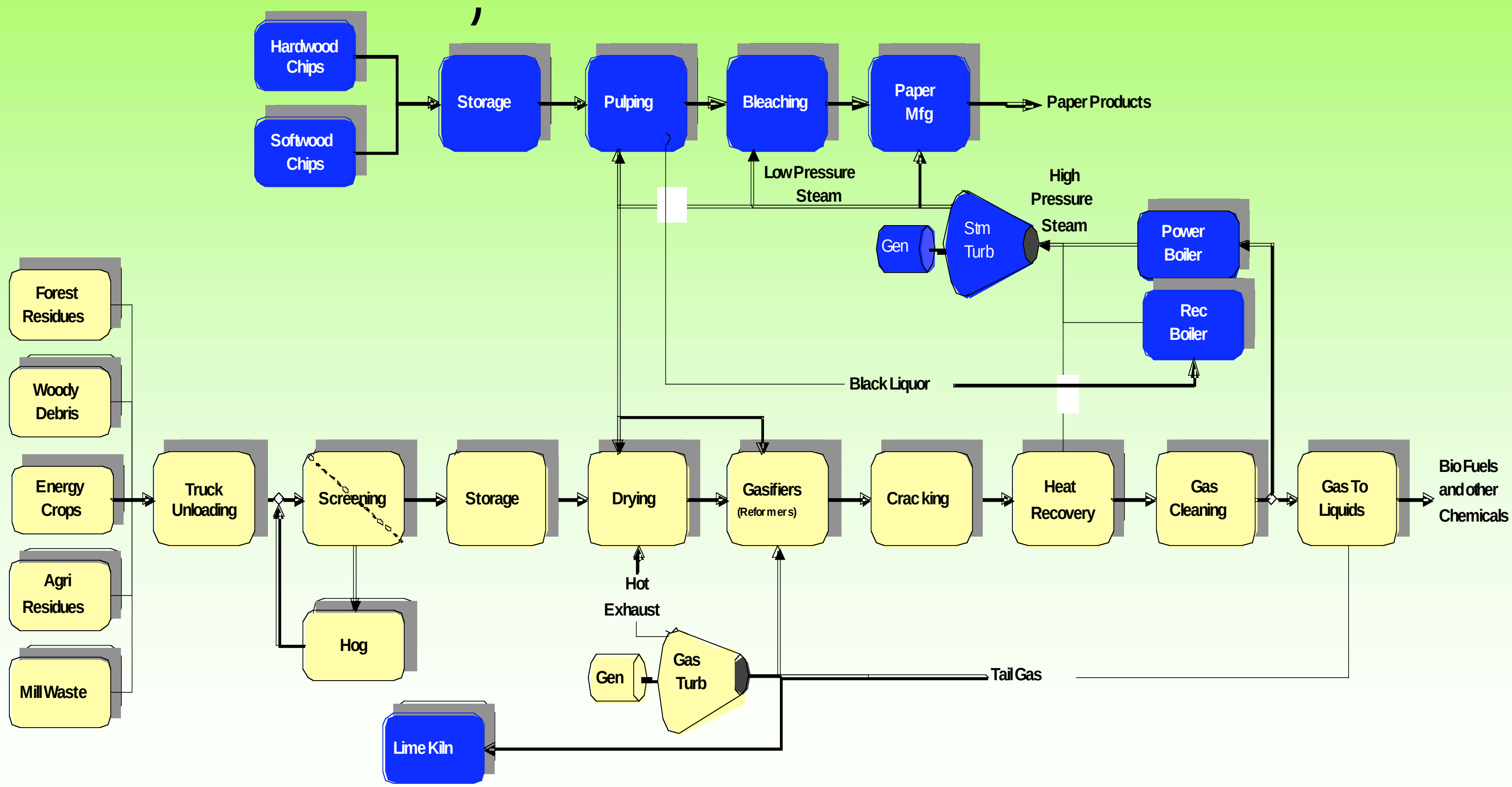
Markets for CO_2

- Current global use of CO_2 in the merchant market is about **20 million t/yr**
- Total U.S. consumption of CO_2 about **8 million t/yr** (does not include EOR or other captive markets)
  - Approximately 70% goes to the food and beverage industry
  - CO_2 associated with ethanol exceeded **11.5 million** t in 2005
  - Price in the merchant market ranges from $30-120/ton delivered depending on the region
  - Raw gas ranges from $3-25/ton also depending on region

Thermochemical Biorefinery

- Thermal process to make syngas from wood and agricultural residues that can then be converted to liquid fuels using catalysts
- Pulp and Paper Industry Agenda 20/20
- Potlatch Feasibility Study for Cypress Bend, Arkansas
  - Integrated facility supplies heat and power for mill
  - Yield: 50-55 gallons per dry ton
  - With oxygen-blown gasifier, also produces concentrated CO_2 stream
  - 1800 ton per day plant could produce about 250,000 tons CO_2 per year

Potlatch Biorefinery Schematic



U. S. Biomass Energy Experience

- Electricity from wood residues:

  312 plants with 6,585 MWe capacity

- Heat from wood residues:

  80% of wood energy use by forest product companies is heat or steam in 3000+ plants

- Cost to produce power
  - $0.05/kWh with free fuel on site
  - $0.09/kWh with fuel at $40/ton

Feedstocks

- Bioenergy Plan for California
  - 30 million dry tons available
    - 4 MDT used today at 28 power plants
  - Ag 29% -- > 50% animal manure
  - Forest 45% -- > 50% slash & thinnings
  - MSW 26%

Biopower: Advanced Combustion Systems that Enable Geologic Sequestration

- The same IGCC processes developed for coal and gas can be used for biomass
- Oxygen-blown combustion or gasification systems could produce power from biomass fuels with relatively pure CO_2 emission streams
- Prototypes not likely to be ready for a number of years

Heat vs Power vs Liquid Fuels

- Heat for thermal applications
  - Each $10 per ton fuel adds $0.63/million BTUs
- Power generation
  - Each $10 per ton fuel cost adds $0.01/kWh
- Liquid fuels
  - Each $10 per ton fuel cost adds $0.10/gallon

Advanced Biomass Power Generation

Fuel requirements

-- Assuming Heat Rate 11,000 BTU/kWh

-- Capacity Factor 80%

Power Output	Biomass Fuel Required
30 MW	212,000 MT
50 MW	353,000 MT
80 MW	565,000 MT

Potential Associated Terrestrial Sequestration

-- Assuming conversion to forest with 20 or 40 year rotations

Power Output	Land Required	Carbon Value after 40 yrs at $10/mtCO_2$
30 MW	53,000 acres	$12.8 Million
50 MW	89,000 acres	$21.6 Million
80 MW	142,000 acres	$34.6 Million

Conclusions

- California can increase terrestrial sequestration by more than 3 billion tons over the next 40 years
- California can reduce net CO_2 emissions from the transportation sector with a proactive program to develop biofuels production in the state linked with geologic sequestration
- Carbon capture and storage can be implemented for ethanol produced in the state
  - minimal additional capital expenditure for carbon capture and storage
  - existing and proposed ethanol production facilities are near promising geologic sequestration sites
- New biofuel and biopower technologies are also promising candidates for carbon capture and storage

Sponsors

- Electric Power Research Institute
- California Energy Commission PIER Program
- U.S. Department of Energy
- Potlatch Corporation
- Arkansas Energy Office
- California Department of Forestry
- U.S. Department of Agriculture

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